ADVERSE AERODYNAMICS EFFECTS OF A HIGH SPEED TRAIN UNDER THE INFLUENCE OF CROSS WINDS, ANALYSIS AND OPTIMIZATION OF WIND FENCE

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Abstract

The research work that here is summarized, it is classed on the area of dynamics and measures of railway safety, specifically in the study of the influence of the cross wind on the high-speed trains as well as the study of new mitigation measures like wind breaking structures or wind fences, with optimized shapes. The work has been developed in the Research Center in Rail Technology (CITEF), and supported by the Universidad Politécnica de Madrid, Spain.

1. INTRODUCTION

1.1. Research background

Due to the high speed increase mileage in the railway traffic and their lightening of the axis weight, is increasingly important the effect of the aerodynamic load produced by the cross winds on the trains. These winds have a negative effect on the stability of trains travelling at high-speed. They can disturb the normal operation, cause damages in the infrastructures or even accidents like derailment or overturning [1]. The train and the infrastructures technological development in the last years has magnified the problem, since train speeds have increased in a considerable way, and each day the infrastructure development increases the stretch of viaduct and on high ground tracks that they increase the pernicious effects of lateral winds.[2].

This research has focused on the design of actions on the infrastructures that are capable of maintaining the speed as high as possible for all the trains running on a line. The main objective of this study is to provide, study and evaluate solutions like wind fences of different morphologies, to mitigate the adverse effects of the aerodynamic load produced by the wind side on the high-speed trains. The installation of barriers on the sides of the railroad tracks is one of the most effective countermeasures and its design is very difficult, because the barriers can disrupt the flow of wind causing harmful effects on trains. It is also an expensive measure, and for this reason its use is still not very common except in high viaducts.

1.2. Objectives

This article is part of a research study. Previous studies developed [3] were used to evaluate the lateral wind effects in order to define the most relevant geometric parameters and make a complete analysis of the effect against side winds in different infrastructures. In the work documented in this article are considered the same experimental setup. The study aim is to design and to evaluate wind barriers with innovative and optimized shapes and morphologies, which solve the problems of the simple barriers. Also, these new proposals of barriers have been analyzed in different situations in order to estimate the viability of the solutions based on the European's Technical Specifications for Interoperability [4].

2. EXPERIMENTAL SETUP

2.1. Description of the environment

The research is focused on the actual conditions, both geographical and operational, of the Madrid-Barcelona High-Speed line (Spain). The most affected zones by the cross wind effects have been selected [5] and the two high-speed trains that operate in this line have been considered in the study (both can circulate up to 350km/h). Infrastructures on which the train runs have also been taken into account: bridges and ground tracks or embankment. Also it has been borne in mind both possible emplacements in the double track railroad.

2.2. Simulation approach.

With two-dimensional analysis and static models, the aerodynamic forces acting on these two vehicles, and the improvements achieved in preventing the harmful cross wind effects by means of wind fence have been measured. A commercial CFD software (Computer Fluid Dynamics) has been used for this purpose. It allowed carrying out a deep analysis of the aerodynamic loads that affect the train in every situation.

The zone in which the analyses have been carried out is a parallelogram of 300 m width and 70 m height, that represents a cross section of the railroad track and its surroundings. Figure 1 shows the computational domain and the main boundary conditions, there are fixed in base of the European regulations about the matter [6].

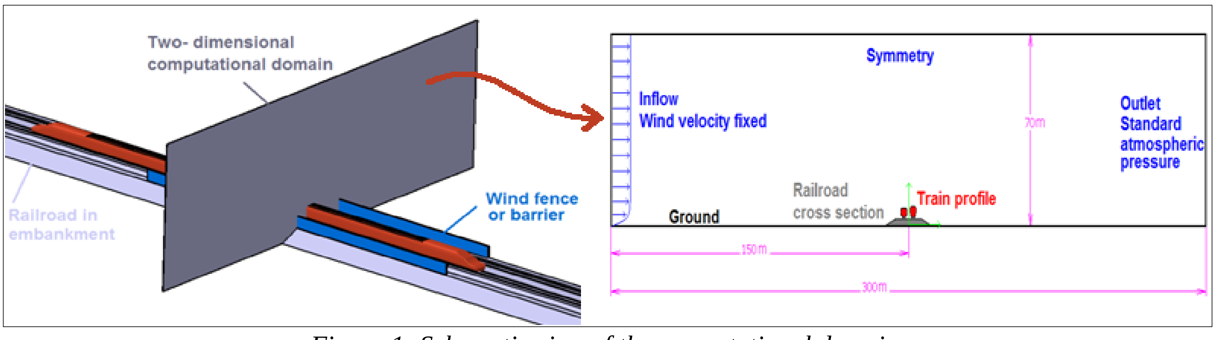

Figure 1: Schematic view of the computational domain

To obtain more accurate results, the mesh used is unstructured Figure 2; in zones where the interest for the results is greater (zones near the train, the ground and the infrastructure) has done a thinner grid. The grid cells are triangular, with the exception of the zone near the train surface. A rectangular grid has been chosen because is more precise and regular. In addition, the software allows an enhancement of the grid depending on the zones where the gradients (of pressure, of speed, etc.) are greater. This tool has been used in order to adapt the grid and refine it. That gives more accurate results in the difficult zones (especially corners of the train).

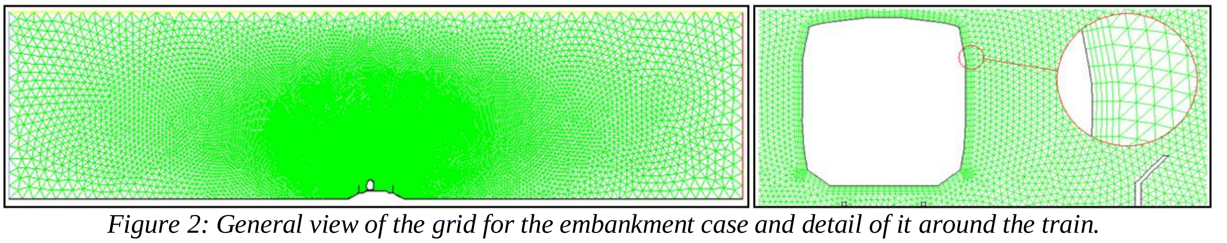
Figure 2: General view of the grid for the embankment case and detail of it around the train.

2.3. Theoretical basics

With the integration of the pressure along the surface of the train the CFD software provides the forces on this and with these forces and knowing the wind velocity (a parameter fixed on the basis of the study of the state of the art) have been calculated the non-dimensional coefficients for each situations. Due to the fact that they are non-dimensional, these coefficients allowed an effective comparison among different situations. The most important coefficient for this study is the side force coefficient (C_x), since a study of the lateral train dynamics opposite to the strong cross winds is required

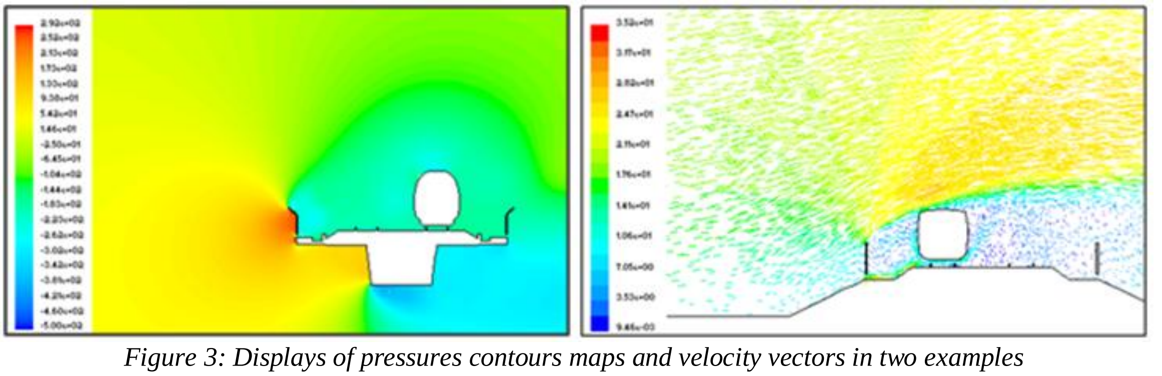
Figure 3: Displays of pressures contours maps and velocity vectors in two examples

Also the pressure contours maps and the velocity vectors were studied. These allow observing the points where higher pressures are obtained and to observe the streamlines, both diagrams are very useful graphs for the effective design of the barriers Figure 3.

3. SIMULATION AND ANALYSIS

In order to achieve clearly the aims of the study, it has been divided into a first part focused on the design of an optimal barrier in all situations studied, and a second part in which we evaluate the feasibility of this best solutions obtained.

3.1. Test to optimize the barrier design.

The optimization tests are made to achieve the design of a barrier that is as effective as is possible for the protection of both trains on viaduct and on embankment. It is important to look for a balance between the forces on the trains placed in the windward track and in the lee track. To take into account these aspects the concept of efficacy is described as:

$$Efficacy(\%)=\frac{C_0-|C_h|}{C_0}*100 \qquad \text{(Eq. 1)}$$

In this equation (Eq. 1) C_o is the value of the drag non dimensional coefficient (lateral affectation coefficient and when the barrier height is zero and Ch is the value of C_x (side force coefficient) or C_y (lift coefficient) when the train is protected by the barrier that is being compared. This efficacy coefficient allows evaluating the improvement in the side and lift affectation that implies the barrier with regard to a situation without barrier. The absolute value is considered to evaluate both the affectation in favour of the wind and the affectation caused by the depressions between train and barrier that force the trains to counter wind [3].

Have been simulated situations with infrastructure type of embankment and viaduct, with different models of train and located in both tracks (leeward and windward). It also have done simulations with different types and heights of barriers and various aerodynamic solutions, such bending angles on the top, barriers with hollow lower and combinations of both. This made possible to compare multiple solutions, and to adapt the characteristics of the new devices to the specific situations in which higher protection is required. Within the multiple aerodynamic solutions that have been studied there are two that stand out due to its good results:

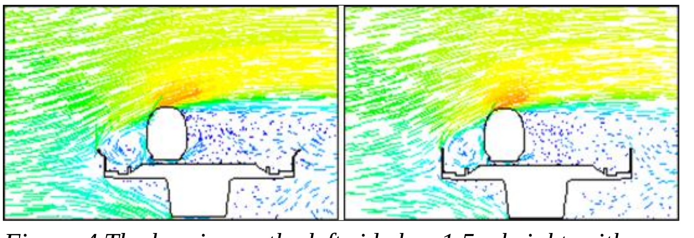

Figure 4 The barrier on the left side has 1,5m height. with spoiler. It is equivalent, in terms of side affectation, to the barrier of 1.75 m height (right picture).

With the use of railroad outward-oriented spoilers, the streamline pass above the train placed at the windward track, achieving efficiencies similar to those obtained with higher barriers. This means that the use of spoilers leads to a result as the height of the barrier appears greater than it is indeed.

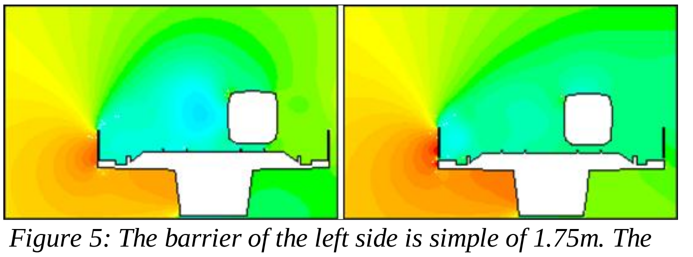

Figure 5: The barrier of the left side is simple of 1.75m. The barrier of the right is 2m and has a small gap. This one, reduces considerably the depression between the barrier and the train (blue areas).

Another solution that gives very good results is the addition of lower gaps. These gaps reduce the efficiency protection of the barrier on the train of windward, but they reduce more drastically the vacuum effect that withstands the train placed in the lee track to counter wind. Its use together with higher barriers gives very good global results.

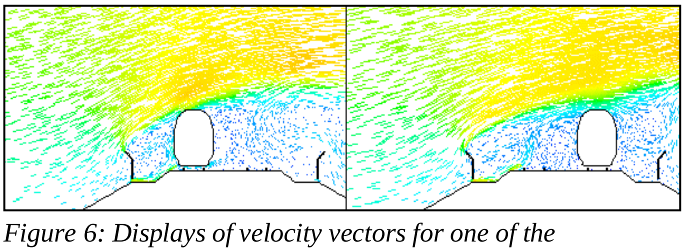

Figure 6: Displays of velocity vectors for one of the simulations. The trains are SIEMENS type, and the barriers were the optimum obtained for embankment.

The combination of both solutions, the outward oriented spoilers and the lower gaps, is an alternative barrier design which gives excellent overall results in both track and in both infrastructure.

In the viaduct tests a barrier (Figure 7) was obtained that has a 96% of global efficacy (It takes into account the average of the efficacy of the four possible cases, combinations of both trains in both possible situations in the double-track).

For the case of embankment three barriers (Figure 7) were obtained that have good global efficacy values but none with the level of efficacy obtained in the viaduct case. The situation in viaduct cases is more restrictive, but the protection with barriers is more effective.

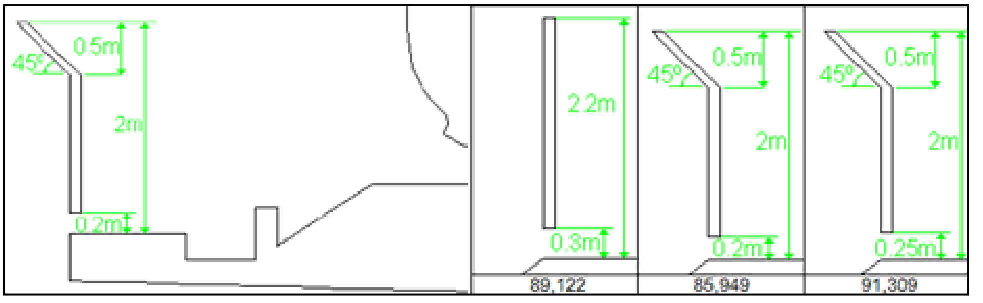

Figure 7: Left: Optimal barrier for the viaduct test. Right: Barriers for the case of embankment.

3.2. Feasibility study.

To verify the obtained results a feasibility study was realized. Simulating the situations with the ideal barriers obtained with an extreme wind gust velocity of 40m/s, it was calculated, depending on the force on the train protected by the barrier, the wind velocity equivalent for this force. The protection with the optimum barriers achieves that the wind was equivalent to 11m/s in viaduct and to 14m/s in embankment in the worst of the four possible cases. In both infrastructures these values do not suppose a limit in the train speed according to the European Technical Specification of Interoperability [3].

4. CONCLUSIONS

The different morphologies of barriers tested, have allowed compare different solutions, and adapt its way to those specific conditions that need more protection, with what has been achieved designs best barriers, who minimize the aerodynamic forces on the surface of the train for each of the situations. The results obtained have been compared with the experimental information of other studies and projects [7][8]. It has verified that the installation of the designed barriers reduce the side affectation of the crosswind up to values that would not require, even for extreme wind conditions, restrictions on the train traffic speed.

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